2008-12

Analysis of employment of a Disaster Relief Damage Assessment System using discrete event simulation

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NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

MBA PROFESSIONAL REPORT

Analysis of Employment of a Disaster Relief Damage Assessment System Using Discrete Event Simulation

By: **Richard J. Bridgett**
December 2008

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REPORT DOCUMENTATION PAGE			*Form Approved OMB No. 0704-0188*
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington DC 20503.			
1. AGENCY USE ONLY *(Leave blank)*	**2. REPORT DATE** December 2008	**3. REPORT TYPE AND DATES COVERED** MBA Professional Report	
4. TITLE AND SUBTITLE Analysis of Employment of a Disaster Relief Damage Assessment System Using Discrete Event Simulation			**5. FUNDING NUMBERS**
6. AUTHOR(S) Captain Richard J. Bridgett, USMC			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000			**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING /MONITORING AGENCY NAME(S) AND ADDRESS(ES) N/A			**10. SPONSORING/MONITORING AGENCY REPORT NUMBER**
11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.			
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.			**12b. DISTRIBUTION CODE**

13. ABSTRACT (maximum 200 words)

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14. SUBJECT TERMS Discrete Event Simulation, Damage Assessment System, Disaster Relief/Humanitarian Assistance			**15. NUMBER OF PAGES** 71
			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	**18. SECURITY CLASSIFICATION OF THIS PAGE** Unclassified	**19. SECURITY CLASSIFICATION OF ABSTRACT** Unclassified	**20. LIMITATION OF ABSTRACT** UU

NSN 7540-01-280-5500 Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18

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ANALYSIS OF EMPLOYMENT OF A DISASTER RELIEF DAMAGE ASSESSMENT SYSTEM USING DISCRETE EVENT SIMULATION

Richard J. Bridgett
Captain, United States Marine Corps

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF BUSINESS ADMINISTRATION

from the

NAVAL POSTGRADUATE SCHOOL
December 2008

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This project uses discrete event simulation to model and analyze the process of setting up and employing a damage assessment system for information-gathering after a disaster. The process that is modeled was originally performed as a live simulation in May of 2008. The live simulation experiment was conducted by a research team affiliated with the Naval Postgraduate School (NPS), including the author, and was based on a post-tsunami scenario that combined numerous surveillance and communications technologies. With information obtained from this experiment, a discrete event simulation model was created to accurately represent the live simulation. The model was then enhanced to include realistic variability for all processes. In addition, further enhanced models were created to simulate likely equipment failures and weather delays in order to estimate how long the process would take given these various conditions. The addition of delays to the model resulted in more realistic cycle times giving the project increased validity. The project provides the Disaster Relief/Humanitarian (DR/HA) research community a realistic analysis tool for assessing the process of setting up and employing a damage assessment system following a disaster and the results give an expected completion time and range under the conditions modeled.

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ACKNOWLEDGMENTS

I would first like to thank my family for enduring my extremely random schedule and sticking by me during my time at NPS. This project was quite the adventure and has taught me a great deal not only about the topic but about myself as well. Thank You and I Love You!

Second, I would like to thank the team members of COASTS 08, specifically the Project Director and Deputy Director, James Ehlert and Ed Fisher, respectively. You two provide an incredibly enriching opportunity to those who are willing to accept it and I will never forget the time spent with the team or the relationships that were forged, at home and abroad. I wish you both many more years of success with the program and will keep COASTS in mind throughout my future endeavors. Chok Dee Khrap!

Next, I would like to thank Ms. Claire Fess, Commander Phillip Gonda, and Dr. Keebom Kang. You all believed in me from day one and went to bat for me, making it possible for me to travel with COASTS and study abroad, despite the fact traveling to the degree that I did was unprecedented. You stuck with me and I hope I have not let you down. Please call on me at any point in the future if there is something I can do for you. Semper Fi!

Finally, I would like to thank my Project Advisor, Dr. Susan Heath. You were just what the doctor ordered for ole Ricky B and I don't regret for a minute the day I walked in your office and begged you to take on my project. You have been patient, forgiving, and a Godsend during this year pushing me when I needed being pushed and backing off when I needed space. I have a great deal of respect for you and wish you all the best while at NPS and beyond. Thanks!

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LIST OF ACRONYMS AND ABBREVIATIONS

COASTS	Cooperative Operations and Applied Science and Technologies Studies
COTS	Commercial Off-the-Shelf
DES	Discrete Event Simulation
DR	Disaster Relief
GPS	Global Positioning System
HA	Humanitarian Assistance
HFN	Hastily Formed Network
HN	Host Nation
JOCC	Joint Operations Command Center
LOS	Line-of-Site
MECP	Mobile Emergency Command Post
MUAV	Mini Unmanned Aerial Vehicle
NGO	Non-Governmental Organization
PCF	Patrol Craft, Fast
PDA	Personal Digital Assistant
RTAF	Royal Thai Air Force
RTN	Royal Thai Navy
SATCOM	Satellite Communications
STOL	Short Take Off and Landing
VHF	Very High Frequency
VOIP	Voice Over Internet Protocol

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I. INTRODUCTION

Given the high number of disasters over the past decade both at home and abroad, a great deal of attention has been given to the study of Disaster Relief/Humanitarian Assistance (DR/HA), likely due to heightened levels of global awareness made possible through advances in communication technology.

Within the first 24 hours following a disaster, a myriad of activities must occur, activities such as search and rescue operations, triage and emergency medical services, and the maintenance of civil order and public safety. One common thread among all of these activities is that they are time sensitive and require timely information to support a great deal of coordination across multiple agencies.

The specific problem addressed in this project, which was prevalent during Hurricane Katrina, is the lack of surveillance and damage assessment systems that can be quickly deployed and efficiently employed, functioning independently from any existing systems, and providing reliable communications for information gathering and coordination during this critical period. This type of system could provide emergency and relief agencies a common operational picture, exponentially increasing their situational awareness and, in turn, making it possible to provide more efficient support to the victims. Without this new found awareness, relief agencies will not know where to respond, what personnel, equipment and supplies are needed, or what needs to be procured. Though most governments, local or national, do have departments established to handle such crises, most do not have a "plan B" in the event the existing communications infrastructure is destroyed. For underdeveloped countries such as Sri Lanka, Cambodia, Pakistan, Indonesia, and Thailand, who lack a robust infrastructure and readily available resources, a system such as this could potentially save thousands of lives that may have otherwise been lost.

In May 2008, the Cooperative Operations and Applied Science and Technologies Studies (COASTS) team conducted a live experiment using a data collection system aimed at filling the previously mentioned "awareness gap" following a disaster. The

system was comprised of numerous commercial off-the-shelf (COTS) technologies which were fielded and operated by Naval Postgraduate School (NPS) students with the aid of technology representatives. The COASTS experiment was used to test and demonstrate the capabilities and value of an independent damage assessment system, consisting of multiple individual technologies, being employed following a tsunami with an end goal of sending a comprehensive damage report from the Joint Operations Command Center (JOCC) to all the agencies that require it.

The May experiment was based on a post tsunami scenario script developed by the COASTS team. The experiment was preceded by numerous test runs the week prior to ensure the conditions were set for a successful test. During these practice runs, it became very apparent that the system had to be employed in favorable conditions and factors such as high winds, heavy rain, or random equipment failures such as power outages significantly degraded the data collection systems performance. Despite the setbacks during the test runs, COASTS was able to conduct a successful live simulation and determined that the data collection system was effective and capable of completing the mission.

Live simulation experiments are inherently limited, since they can only be carried out a small number of times. The COASTS experiment was no exception as the full simulation was only run once. Therefore, random factors such as weather, climate, geography and random failures of personnel and equipment were only represented by a single data point in the one simulation run. This makes it impossible to understand the effects of these factors on the performance of the system. It is for this very reason that discrete-event simulation (DES) modeling is such an excellent resource.

The value of using DES modeling lies in the fact that the parameters and inputs of the system being tested can be altered over multiple simulation runs. By altering these, it allows for that system to then be tested under a whole host of situations, in turn giving the researcher an ideal of how the system might perform given those conditions.

The primary goal of this project is to expand on the COASTS experiment and explain how the data collection system would operate under more realistic conditions. This is done by first building a model based on the COASTS script using discrete event simulation modeling software and information obtained from the COASTS experiment. Using the Script Model as a template, a Baseline Model is then created by changing the activity times that were constant in the Script Model to activity times drawn randomly from a probability distribution to reflect more realism and variability. The Baseline Model is then enhanced to reflect possible equipment failures as well as delays due to inclement weather. The results of these models are summarized and analyzed and recommendations are made.

Looking ahead, Chapter II provides a background of COASTS to include additional information on the problem, a description of the live experiment, and characteristics of system equipment. Chapter III describes the simulation model and how it was built, states the model assumptions, and illustrates the creation of the Script and Baseline Models. Chapter IV explains how the experimental models were created and is the precursor to Chapter V which provides results and analysis of the experimental models. Finally Chapter VI summarizes the project, conclusions and recommendations.

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II. RESEARCH BACKGROUND

This chapter provides the background information about the COASTS organization. The chapter then touches on the description and setting for the COASTS live experiment, to include a brief description of the data collection system and equipment tested. The chapter wraps up with a short summary of the tsunami script followed by the COASTS experiment results.

A. THE COASTS ORGANIZATION

COASTS is a research based, NPS affiliated, student run organization. Founded in 2004 by NPS Research Professors Brian Steckler and James Ehlert, COASTS

> organizes and executes live experiments to demonstrate the capabilities of low cost, state-of-the-art, unclassified networked air, ground, and maritime equipment for the purposes of providing real time information to tactical and remote decision makers. The COASTS team emphasizes the use of COTS technologies using tailored scenarios to test and evaluate areas of research that are critical to both U.S. and international security objectives. In FY2008, the COASTS objectives encompassed field experimentation and technology demonstrations in the U.S., Thailand, Malaysia, Singapore, and Indonesia.[1]

B. DESCRIPTION OF LIVE EXPERIMENT

The location chosen by COASTS to conduct the live experiment in May of 2008, also known as field experiment V (FEXV), was Prachuap Khiri Khan, Thailand, on a Royal Thai Air Force (RTAF) base which is home to Wing 5 (Figure 1). The base is located in Ao Manao Bay which is southeast of Prachuap Khiri Khan, on the Gulf of Thailand (Figures 1&2). Wing 5 includes an RTAF AU-23 Monoplane squadron and hosted the experiment. Wing 5 conducted numerous coordination meetings with COASTS and provided a large portion of the requisite personnel and equipment support for the experiment. From the COASTS side, approximately 80 personnel, including the

[1] Taken from COASTS 2008 Mission Power Point Brief dated 3 October 2007.

author, attended the May experiment ranging from NPS students and faculty, Department of Defense personnel, civilian contractors, and representatives from the Office of the Secretary of Defense.

Figure 1. Map of Thailand Showing Prachuap Khir Khan, the Experiment Site on the Gulf Coast (From: Internet, Google Images)

Figure 2. Map of Ao Manao Bay, Wing 5 Showing the RTAF Base and Airstrip (From: Google Earth)

1. Equipment Tested During COASTS Experiment

During the live experiment, there were five main data collection and transmission platforms that comprised the system being tested. These were: (1) the RTAF's AU-23 Peacemaker Monoplane; (2) the AeorVironment Raven RQ-11b Mini Unmanned Aerial Vehicle (MUAV); (3) the Royal Thai Navy's (RTN) Pattani-Class Patrol Craft, Fast (PCF); (4) the JOCC; and (5) a Mobile Emergency Command Post (MECP) that utilized an experimental cell phone technology developed at NPS known as Twiddlenet. The

following subsections provide a brief description of each technology as well as its purpose during the COASTS experiment and Figure 3 provides a more detailed view of the experiment area to include how various equipment was connected to the JOCC.

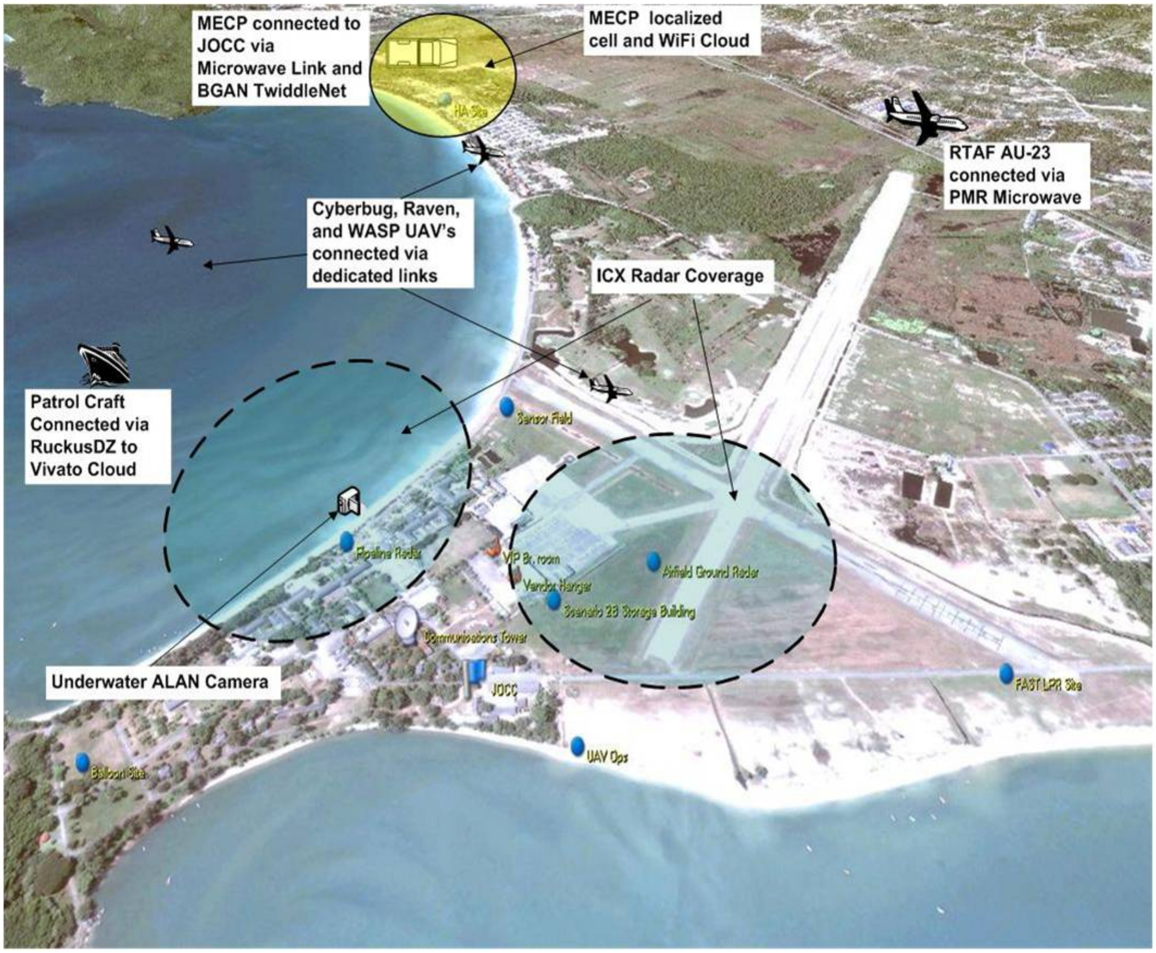

Figure 3. Aerial View Showing How AU-23, PCF, MUAV, and MECP were Communicating with the JOCC (From: COASTS Network P-Point)

a. Royal Thai Air Force's AU-23 Monoplane (Peacemaker)

The AU-23 Peacemaker is essentially a modified version of the Swiss Pilatus PC-6 Porter civilian utility aircraft. First introduced in the late 1950s, the currently used turboprop version was introduced in 1961 and then upgraded in 1963 to its

current engine configuration. Within the United States, the AU-23 was produced by Fairchild Industries who in turn sold 35 of the aircraft to the Royal Thai Air Force following Vietnam.

The AU-23 is famous for its short take-off-and-landing (STOL) capability requiring little more that a soccer field to do both. Operated by a single pilot, the AU-23 and can hold up to 10 passengers, has a maximum speed of 153 mph, a maximum range of 870 nautical miles and a maximum operating altitude of 25,000 ft. Since the RTAF variant is armed, it is used primarily for counter-insurgency operations making it a perfect fit for surveillance.

During the live experiment, the AU-23 was equipped with very high frequency (VHF) communications as well as a video capability. It was launched immediately for the purpose of providing the JOCC initial reports of the disaster area to include route information that could be used to direct the MECP.

b. Raven RQ-11b Mini Unmanned Aerial Vehicle

The Raven RQ-11b or Raven B is a MUAV manufactured by AeroVironment, Inc. Its purpose is low altitude surveillance and reconnaissance and is used by militaries throughout the world. Due to the system's mobility and rapid deployment capability, is currently regarded as the "most prolific unmanned aerial vehicle system in the world today."[2]

The Raven B is a hand launched MUAV that can be guided by a ground station or fly autonomously using advanced global positioning system (GPS) navigation. It power plant is a battery powered electric motor giving it a limited endurance of 60 to 110 minutes depending on battery type.

[2] Wikipedia, http://en.wikipedia.org/wiki/RQ-11_Raven

> The Raven B has a line-of-site (LOS) range up to 10 kilometers, speed from 32-81km/h, and a maximum operating altitude of approximately 500ft above mean ground level (MGL) or 14,000ft above mean sea level (MSL). The Raven can deliver real time color or infrared imagery to the ground control and remote viewing stations.[3]

During the live experiment, the Raven B was launched from the JOCC site only after the MECP had reached its destination. Once over the disaster area, the MUAV was used to survey the damage and provide real time color video back to the control station located close to the JOCC which was then routed via a wireless link to the JOCC.

c. *Royal Thai Navy's Patrol Craft, Fast*

Powered by a diesel chassis and large enough to house a small crew, the PCF packs enough punch to not only patrol the calm riverine and coastal water but to also endure the choppy seas when required. The PCF's relatively small size makes it a perfect fit for such missions as anti-smuggling, anti-trafficking, fishery enforcement, and anti-piracy.

During the live experiment, the PCF was dispatched to the disaster area in order to augment the aerial assessment provided by the AU-23 and to provide a coastal perspective of the damage. Its primary mission was to transmit a voice report back to the JOCC via VHF communications and then loiter in the area providing aid where needed.

d. *Joint Operations Command Center*

The JOCC was located on base in a pre-existing building located out of the disaster area but close enough to it that the aerial platforms could perform their mission. The JOCC was the central coordination point for the MUAV operator, MECP Team, and additional support personnel prior to, and during, the COASTS experiment. The JOCC was set-up so that all could obtain and maintain a common operational picture of what was occurring. It was the nerve center of the experiment and was home to all key

[3] AeroVironment website, http://www.avinc.com/uas_product_details.asp?Prodid=1

crisis team personnel. All functions of the experiment were controlled from the JOCC to include the commands for launch and recovery of aerial and ground platforms, audio and video reception/transmission, and report generation/dissemination.

e. Mobile Emergency Command Post and Twiddlenet

As previously mentioned, the MECP represented any ground platform that has the ability to safely transport a specified amount of personnel, supplies, and data collection equipment into the disaster area for purposes of damage assessment. For the purposes of this experiment, the MECP platform was a 10-passenger van. The MECP also performed emergency medical services once in place but this is a secondary mission to the primary of data collection.

The key technology of the MECP is the NPS-developed Twiddlenet. The attraction to Twiddlenet is that it can tie cell phones and personal digital assistants (PDA) into a hastily formed network (HFN) created by the crisis team. This capability is extremely beneficial and has enormous applicability when the disaster area has lost commercial cell phone communications. During the live experiment, the Twiddlenet operating within the MECP performed the mission of providing video and data transmissions back to the JOCC.

2. Brief Summary of Live Experiment Scenario Script

The post tsunami scenario script developed and executed by COASTS can be seen in its entirety in Appendix A. The following is a brief summary of the script and what occurred. (During the live experiment, what was supposed to happen according to the script and what did happen were close enough for the purposes of this project that it can be summed up as "what occurred.")

Approximately one hour after a tsunami hits the coastline, the crisis team, consisting of all scenario participants and equipment, is assumed to have already arrived near the disaster site and requests permission from local authorities to survey the affected area. Once permission to survey the disaster area is given, the simulation clock begins. Approximately one hour of coordination and preparation takes place and it is at the

conclusion of this hour that the equipment is ready to be employed. The Hastily Formed Network (HFN) used to tie all crisis team equipment together is also established as part of the JOCC preparation during the one-hour coordination and equipment preparation window allowing the system to operate independent of local communications infrastructure. The timeline below represents simulation time, not real clock time during the live simulation:

- 0:00 to +1:01 the equipment is prepped, coordination takes place, and the HFN is established
- +1:02 the AU-23 Monoplane takes off for purposes of surveying the disaster area
- +1:03 the MECP departs the base enroute to the affected area for purposes of damage assessment and triage
- +1:15 the AU-23 arrives over disaster area and starts streaming video back to JOCC via very high frequency (VHF) communications
- +1:15 the RTN patrol boat arrives in the disaster area and provides a damage assessment using Voice Over Internet Protocol (VOIP), remains in area until end of scenario

(Timeline Compression) *60 minutes simulated elapsed*. At this point in the script, there is a 60-minute timeline compression thereby adding one hour to the simulation timeline. During this simulated hour, routes are determined into the disaster area for disaster relief teams. The JOCC relays this information to the MECP Team who was already on the move to the disaster area and the AU-23 uses loiter capability to remain over the disaster area and provide continued support until end of scenario.

- +2:20 MECP arrives at disaster site and begins setting up links, MUAV launched from base to support MECP
- +2:40 MECP setup complete, data transfer with JOCC ongoing via satellite communications (SATCOM), MUAV providing JOCC with video feed of disaster area

- +2:45 JOCC sends disaster reports to host-nation command center and local non-governmental organization (NGO) headquarters

3. Brief Summary of Live Experiment Results[4]

a. Pre-Experiment Test Runs

The final COASTS experiment was preceded by a handful of practice experiments, or test runs. There were a number of hang-ups just prior to and during these practice experiments such as a power outage at the JOCC. Since the JOCC is the hub for all communications as well as the centerpiece for the HFN, losing power became a critical situation. Every activity in the system was eventually affected by the power outage and having a backup power source became a key learning point. In addition to the JOCC power outage, a severe rainstorm popped up during one of the test runs bringing with it high winds, heavy rain, and lightning. The storm wreaked havoc on the system as a whole resulting in the grounding of all aircraft and damages to the MUAV and HFN infrastructure. These particular occurrences in addition to a few more potential issues are used in experimental scenario development contained in Chapter IV.

b. Live Experiment

During the full live experiment run the HFN proved to be reliable and favorable weather conditions allowed the AU-23 and MUAV to get in the air, loiter over the disaster area, and transmit data back to the JOCC for use elsewhere in the scenario. The MECP kept to the timeline and was able to accomplish all tasks including image transmission and the delivery of emergency medical services to the victims within its immediate area. By all accounts the live experiment was a success and the data collection system proved to be capable of operating under favorable conditions.

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[4] Summary taken from FEX V Daily Sitrep (Final) from Tuesday, May 27, 2008 (Appendix B)

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III. SCRIPT AND BASELINE MODEL

Chapter III begins with assumptions and key metrics for all models developed as part of this project. Next, the construction of the Script and Baseline Models is described to include details about the commonalities of the models such as flow, activities, and outlines what is contained in each. Finally, the Script and Baseline models are compared using the metrics defined below.

A. ASSUMPTIONS

The overarching objective of this project is to expand on the live experiment in order to test the performance of the entire system under a variety of circumstances, not to test the individual equipment, technologies, and preparation that made it possible. Therefore, assumptions are necessary. The first two models constructed for this project were the Script Model that contains no variability but matches the live simulation script and a Baseline Model where probability distributions were inserted for timed activities to reflect real world variability. The Baseline Model also serves as the model from which the experimental models were created. The following is a list of assumptions which apply to all models:

- The disaster area is within range of all equipment
- The weather conditions ultimately permit the systems employment, although may cause delays
- All equipment and personnel are ultimately functional although may experience recoverable failures

B. METRICS

In keeping with the main purpose of this project, which is to expand on the COASTS experiment and explain how the data collection system would operate under more realistic conditions, a metric of *total time to mission completion* is used to evaluate and compare all models. For the purposes of this project, *total time* means the time it

takes for the JOCC to generate and transmit a comprehensive damage assessment to the non-governmental organizations (NGOs) supporting the DR/HA effort. This step is what all other activities in the system are working towards, the step that will take all compiled data and turn it into usable information. Until this happens, it is assumed that the only persons who know the full extent of the damage are the victims and the HA/DR personnel on site working to produce the assessment.

That said, there are additional metrics that can be useful, such as the time it takes for each entity to survey the disaster area and transmit a damage assessment to the JOCC. These metrics can be extremely helpful when examining the effects of temporary failures and weather delays in the enhanced models, further demonstrating how problems with one entity can significantly delay all others.

C. SCRIPT MODEL

The Script Model was built according to the COASTS script with all times constant. The model times are *simulation times* as opposed to *real times* and are based on an interpretation of the script which lasts 165 minutes. What was not built into the Script Model was the time it takes for the crisis team to travel to the disaster area, link up with the host nation (HN) government, and gain permission to setup and employ the system. This cannot be projected due to the global nature of disasters, various modes of travel, requirements of and relationships with different governments, and a whole host of other variables beyond the control of all involved.

1. Script Model Flow

The simulation model was developed by first creating a precedence diagram for all the activities involved in the mission. As described later, the Script and Baseline Models have exactly the same flow. The only difference between them is the *activity times* which are constant in the Script Model and probabilistically distributed in the Baseline Model. Subsequent paragraphs will provide a description of the model flow as

well as flowchart snapshots (Figures 4&5). The following precedence table (Table 1) was compiled to construct the model flow and the activity letters in the table correspond to the activity letters in the flowchart figures.

ACTIVITY PRECENDENCE TABLE		
ACTIVITY DEFINED	**ACTIVITY**	**PRECEEDS**
PREP AU-23	A	F
PREP JOCC	B	C
PREP PCF	C	G
PREP MECP	D	H
PREP MUAV	E	I
AU-23 LAUNCH AND TRANSIT TO DISASTER AREA	F	J
PCF LAUNCH AND TRANSIT TO DISASTER AREA	G	K
LAUNCH MECP AND BEGIN TRANSIT TO DISASTER AREA	H	M
MUAV LAUNCH AND TRANSIT TO DISASTER AREA	I	Q
AU-23 SURVEYS DISASTER AREA AND SENDS DATA TO JOCC	J	L
PCF SURVEYS DISASTER AREA AND SENDS DATA TO JOCC	K	L
JOCC PROCESSES DATA FROM AU-23 AND PCF, SENDS ROUTE DATA TO MECP	L	M
MECP RECEIVES ROUTE DATA FROM JOCC	M	N
MECP TRANSITS TO DISASTER AREA	N	I,O
MECP SETS UP, SURVEYS, AND SENDS DATA TO JOCC	O	Q
MUAV SURVEYS DISASTER AREA AND SENDS DATA TO JOCC	P	Q
JOCC PROCESSES DATA FROM MECP AND MUAV, SENDS DAMAGE ASSESSMENT TO NGO’S	Q	END

Table 1. Activity precedence table for use with model flowchart (Figures 4 & 5)

The activity flow in the model commences with the Tsunami strike which leads to the crisis team link-up with local government officials (both civil and military). Once the link-up takes place and authorization is given to the COASTS team to survey the disaster area, a preparation phase starts that includes the crisis team establishing the HFN and prepping all equipment. The AU-23 is launched first for the purpose of providing initial damage assessments and to report back with usable route information that can be passed from the JOCC to the MECP. As the AU-23 launched, the MECP is dispatched to the disaster area with the intention of receiving route updates on the move in order to find its

intended destination. Also at the same time, the PCF is directed to proceed from a nearby port to the shoreline of the disaster area in order to provide reports based on the coastline perspective. After a short transit time, the AU-23 arrives at the disaster area and begins transmitting video and damage assessments back the JOCC. Similarly, after some transit time, the PCF arrives at the disaster area and communicates damage assessment information to JOCC. The JOCC uses all this information to generate route information that can be passed along to the MECP (Figure 4).

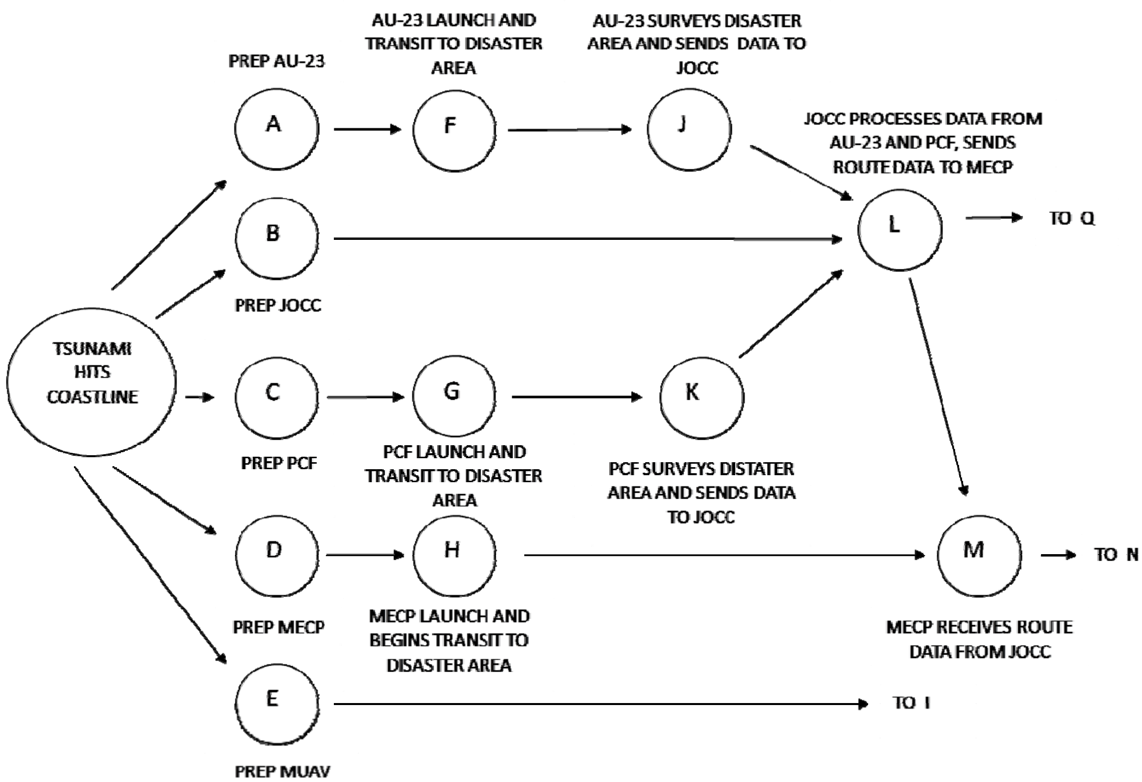

Figure 4. Flowchart Snapshot Showing Tsunami Strike, Preparation Processes, and Data Transmissions To and From JOCC

Upon the MECP's arrival at its final destination, the signal is given for the MUAV to launch. The MECP then proceeds to set up and the MUAV is directed over the disaster area by the JOCC in order to survey the affected area and transmit assessment data back to the JOCC. The MECP is now set up, the MUAV is over the disaster area,

and both are transmitting video and data back to the JOCC. The JOCC uses information from the AU-23, PCF, MUAV, and the MECP to complete the final system step of transmitting the summarized damage assessment report to the NGO's (Figure 5).

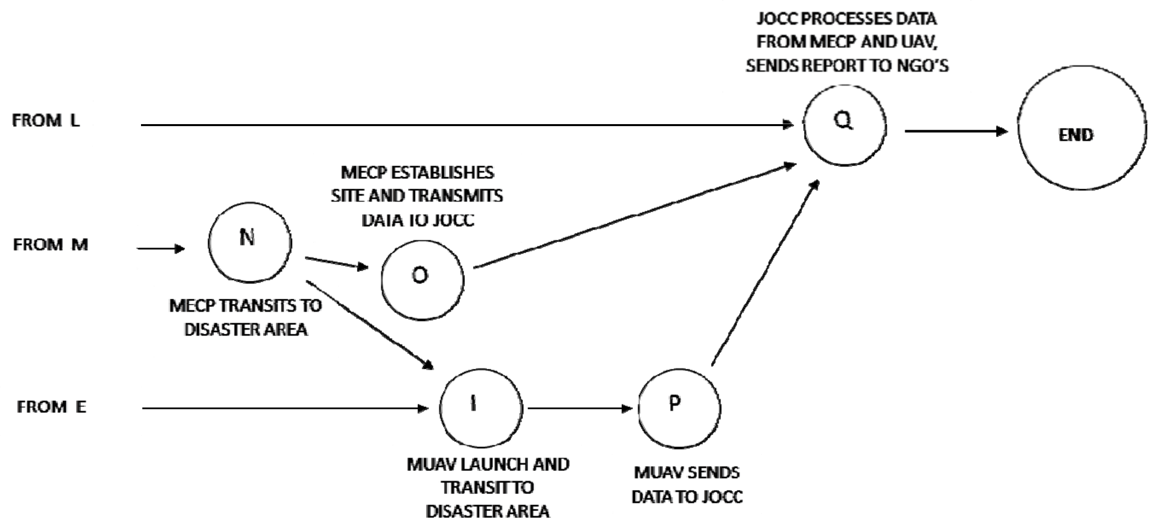

Figure 5. Flowchart Snapshot Showing JOCC's Transmission to NGO's

2. Script Model Creation

The Script Model was created with processes for the activities defined above and flows that follow the description given above. Details about the entities and the processes within the Script Model are described below. As previously noted, the Script Model was based solely on the COASTS Tsunami scenario script and contains no variation, meaning all process times are constant.

a. Entities

The description and role of each equipment entity have been previously explained in Chapter II. Additional entities, denoted PTP, represent communications between other entities. Table 2 builds on the existing entity information by showing what resources are required for each equipment entity to carry out any process activities. The resources are assigned a representative letter in Table 3 that is referred to in Table 4.

	Entity	Associated Resource
1	AU-23	(a) Air Crew; (b) Pilot
2	PCF	(c) PCF Crew
3	Mini Unmanned Aerial Vehicle	(d) MUAV Pilot
4	PTP	
5	MECP	(e) MECP Crew; (f) MECP Security Team
6	JOCC	(g) JOCC Team

Table 2. Entity information for script model

b. Processes

For processes, all *Type* were standard, all *Actions* were seize-delay-release, all *Priority* were the same (medium 2), *Allocation* was set to value added for each, and all *Units* are in minutes. The table below denotes the constant process delay times and the resources required for each process.

a=Air Crew	b=Pilot	c=PCF Crew	d=MUAV Pilot	e=MECP Crew	f=MECP Security Team	g=JOCC Team

	Process	**Resource(s)**	**Minutes**
1	PREP AU-23	a, b	62
2	PREP JOCC	g	60
3	PREP PCF	c	60
4	PREP MECP	e, f	63
5	PREP MUAV	d	139
6	AU-23 LAUNCH AND TRANSIT TO DISASTER AREA	b	8
7	PCF LAUNCH AND TRANSIT TO DISASTER AREA	c	10
8	LAUNCH MECP AND BEGIN TRANSIT TO DISASTER AREA	e, f	17
9	MUAV LAUNCH AND TRANSIT TO DISASTER AREA	d	15
10	AU-23 SURVEYS DISASTER AREA AND SENDS DATA TO JOCC	a	5
11	PCF SURVEYS DISASTER AREA AND SENDS DATA TO JOCC	c	5
12	JOCC PROCESSES DATA FROM AU-23 AND PCF, SENDS ROUTE DATA TO MECP	g	5
13	MECP RECEIVES ROUTE DATA FROM JOCC	e, f	5
14	MECP TRANSITS TO DISASTER AREA	e, f	55
15	MECP SETS UP, SURVEYS, AND SENDS DATA TO JOCC	e,f	20
16	MUAV SURVEYS DISASTER AREA AND SENDS DATA TO JOCC	d	5
17	JOCC PROCESSES DATA FROM MECP AND MUAV, SENDS DAMAGE ASSESSMENT TO NGO’S	g	5

Table 3. Script Model processes information

D. BASELINE MODEL

The Baseline Model was structured on the COASTS Tsunami scenario script but has been injected with realistic variability by altering all process delay times to a probabilistic delay using a *Triangular* distribution. Since there was no real data available, it is not known what probability distribution and distribution parameters were

most accurate. Therefore, using one of three distributions (*Exponential, Triangular,* and *Uniform*) recommended in the *Arena* book, the *Triangular* distribution was chosen since it is the best represents the distribution of process times for this particular project (Kelton pg.183-185). This distribution calls for *Minimum*, *Most Likely*, and *Maximum* time parameters. All time parameters for the Baseline Model processes delays have been determined by the following methods:

- Information and experiences gained from being present at the live COASTS experiment
- Knowledge gleaned from interacting with the equipment operators
- Answers provided by experiment attendees on questionnaire (Appendix B)
- Ability to make inferences after 19.5 years in service

The following table relates to the Baseline Model and only provides details about the processes and their changes as all other model information is the same as the Script Model. A full view of the Baseline Model as it appears in Arena can be seen in Appendix D.

a=Air Crew	b=Pilot	c=PCF Crew	d=MUAV Pilot	e=MECP Crew	f=MECP Security Team	g=JOCC Team

	Process	**Resource(s)**	**Minutes**
1	PREP AU-23	a, b	30,60,90
2	PREP JOCC	g	30,90,180
3	PREP PCF	c	30,60,120
4	PREP MECP	e, f	30,90,180
5	PREP MUAV	d	10,60,90
6	AU-23 LAUNCH AND TRANSIT TO DISASTER AREA	b	10,30,60
7	PCF LAUNCH AND TRANSIT TO DISASTER AREA	c	20,60,120
8	LAUNCH MECP AND BEGIN TRANSIT TO DISASTER AREA	e, f	10,30,60
9	MUAV LAUNCH AND TRANSIT TO DISASTER AREA	d	15,30,45
10	AU-23 SURVEYS DISASTER AREA AND SENDS DATA TO JOCC	a	10,15,30
11	PCF SURVEYS DISASTER AREA AND SENDS DATA TO JOCC	c	15,30,60
12	JOCC PROCESSES DATA FROM AU-23 AND PCF, SENDS ROUTE DATA TO MECP	g	5,30,60
13	MECP RECEIVES ROUTE DATA FROM JOCC	e, f	1,5,15
14	MECP TRANSITS TO DISASTER AREA	e, f	30,60,120
15	MECP SETS UP, SURVEYS, AND SENDS DATA TO JOCC	e, f	30,60,180
16	MUAV SURVEYS DISASTER AREA AND SENDS DATA TO JOCC	d	5,10,30
17	JOCC PROCESSES DATA FROM MECP AND MUAV, SENDS DAMAGE ASSESSMENT TO NGO’S	g	20,40,90

Table 4. Baseline Model processes information

E. SCRIPT AND BASELINE MODEL RESULTS AND ANALYSIS

The Script Model results did not deviate from the COASTS Experiment scenario that was executed. This model was that way to provide a benchmark that could be built

upon, and also so that enhancements could be added. The results generated by the Script Model (Table 5) follow the script event flow perfectly showing that it took ultimately 165 minutes for the JOCC to send the damage assessment to the NGO's.

Table 5 highlights the difference in times needed to send data from one entity to the next starting at simulation time zero and ending at the time the communications happened. These metrics are our best gauge of how the system functions and can quickly reveal possible problems. The Baseline Model has been replicated 200 times. This number of replications was chosen because it is a large enough sample to produce acceptable *Average* times based on the *Confidence Interval* (value range above and below the average based on the half width) also displayed in Table 5. All *Times* in Table 5 have been rounded to the nearest minute.

****All Time is in Minutes**	Script Model (Constant Delay)	Baseline Model (Triangular Delay, 200 Replications)			
	Time Until Data Sent	Average Time Until Data Sent	Confidence Interval	Min	Max
AU23 to JOCC	75	111	[109, 114]	71	154
PCF to JOCC	75	173	[169, 177]	97	238
JOCC to MECP	80	205	[201, 210]	136	287
MUAV to JOCC	160	327	[322, 331]	225	422
MECP to JOCC	160	372	[365, 378]	233	497
JOCC to NGO	165	423	[416, 430]	293	558

Table 5. Comparison of Script and Baseline Model metrics

The value of the Baseline Model is that it provides a more realistic picture of the system by using a range of possible process times as opposed to assigning a specific value to the processes or shortening them for the sake of the experiment as with the Script Model. Therefore the Baseline Model is the starting point for all experimental models

described in Chapter IV. As expected, the Baseline Model, having been injected with more realistic process times and process time variability, shows that it takes approximately 128 minutes longer to get the damage assessment from the JOCC to the NGO's best case, 423 minutes longer worst case, and 258 minutes longer on average. In essence, based on the simulation results, it takes, on average, seven hours for the damage assessment system to realistically run its course given the parameters listed in Table 4. As previously stated in this chapter, due to time and resource constraints, some of the script activities were not fully acted out during the COASTS experiment which would account for the large time differences in Table 5.

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IV. EXPERIMENTAL MODELS

Once the Baseline Model has been established, the model can be further expanded to include the possibilities of other random events such as equipment failures and bad weather delays. Chapter IV provides details on about the creation of three experimental models that were designed using the Baseline Model as the starting point.

A. EQUIPMENT FAILURE MODEL

Equipment failures are inevitable and inherent part of any system and must be planned for. Failures of this nature are generally random and can be reduced by aggressive preparation, planning and preventative maintenance. However, the possibility of equipment failures can never be eliminated. That said, in order to test this system under more realistic conditions, this model enhancement must be included. The model demonstrates how equipment failures that have been assigned probabilities and triangular delay times can impact the amount of time is takes for reports to be sent across all paths.

Using the Baseline Model as a start point, temporary failure delays were built into the model by first creating a Failure Table within the modeling software using the data in Table 6. Specific data for failure likelihoods were not available due to the fact the COASTS experiment summary did not incorporate failure data; therefore, Probabilities and Down Times in Table 6 are reasonable guesses.

The equipment and problems listed in Table 6 were reasonable estimations based on a combination of factors such as age of equipment, projected reliability of power grid following a disaster and most likely issues based on equipment type. The probabilities and down time associated with these problems were determined much the same way and are a mix of reasonable guesses based partially on real issues that surfaced during the dry runs mentioned at the end of Chapter I.

Equipment	Problem	Probability of Problem Occurring	Time Down in Minutes
AU-23	Gauge Malfunction	5%	1, 15, 60
JOCC	Power Outage	1%	1, 30, 120
MECP	Mechanical Problems	5%	5, 30, 60
MUAV	Battery Not Charged	3%	30, 60, 90
PCF	Engine Will Not Start	5%	5, 15, 60

Table 6. Details of failures built into Baseline Model to create Equipment Failure Model

When creating the *Failure Table*, the failure *Type* for all was time and the formula used to populate the *Up Time* field was based on a discrete probability using the expression: *DISC (probability of problem, UNIF (0, mimimum system run time from Baseline Model), 1.0, 10000)*. For example, the formula for *AU-23 Up Time* is *DISC (0.05, UNIF (0,293), 1.0, 10000)*. This formulation for *Up Time* allows the coding of a probability that the failure will occur during the simulation run. To insure that, if failure was supposed to happen according to the results of the draw from the discrete distribution, that the failure did actually occur, the longest possible *Up Time* for this case was set to 293 minutes, which was determined from the Base Model results to be the fastest time that the simulation could run. Note however, that it is possible for an equipment failure to occur after that equipment has sent its required communication so the failure may not necessarily cause the delay of other activities. This was determined to be the most realistic and effective way to code the failures.

The *Down Time* field was populated using a triangular distribution using the numbers presented in Table 6. Once the failures were created they were associated to the equipment via resources needed to operate the equipment. For example, the *Pilot* is a resource needed to operate the *AU-23* throughout every process; therefore by attaching the failure probability to the pilot, the AU-23 is by probabilistically failed by association. This association to a resource other than the actual equipment was required since the equipment was modeled as an entity rather than a resource. This strategy required a

slight modification to the Baseline Model when it came to the *JOCC Power Outage* failure. Since a power failure affects all data transmission to and from the JOCC, all data transmission activities had to be isolated in their own processes so all necessary resources could be properly required, and therefore all data transmissions properly affected by a failure. Therefore all processes that combined surveying and data transmission had to be split. This allowed for the *JOCC Team* resource, with the power failure attached to it, to be added to all data transmission processes, regardless of which piece of equipment was communicating with the JOCC. The newly added *Send Data* processes for each piece of equipment were given a constant time of 1 minute. Consequently, all process times associated with the *Survey* process were reduced by 1 minute as to not skew the total time required for the *Survey* and *Send Data* processes together. By doing this, the model simulated the failure of all data transmissions, regardless of which equipment failed, injecting additional realism into the model.

B. WEATHER DELAY MODEL

As with equipment failures, bad weather is also something relief workers have to consider. For the purposes of this project, bad weather is defined as heavy rain, flooding, high seas, or high winds, or something of the like which exists to some degree during the disaster response window. The residual effects of weather related disasters such as hurricanes and typhoons are likely factors that will impact the response and must be planned for. The Weather Delay Model is designed to simulate likely delays due to bad weather.

The Weather Delay model used the Baseline Model as a starting point just as the Equipment Failure Model did. Temporary delays were built into the model by creating a Weather entity. The Weather entity was then sent into a decision module that was given the probability of 10%, Every time this decision is true, the Weather entity proceeds to an assign module where it changes the value of a variable named Bad Weather from the initial value of zero to a new value of 1 (Figure 7).

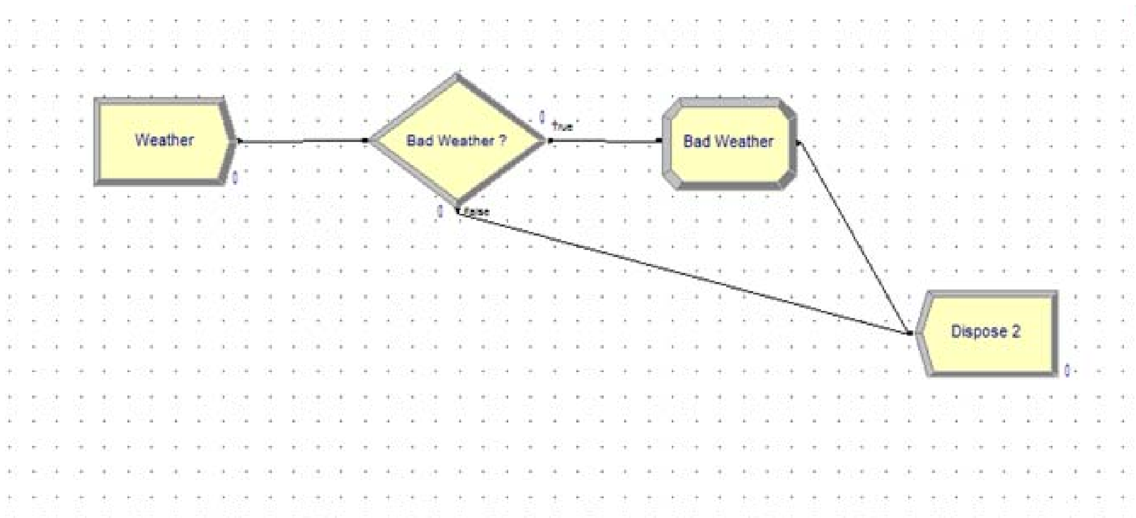

Figure 6. Snapshot of Arena 10.0 Module Additions Needed to Complete the Weather Delay Model

The variable Bad Weather has been linked to each process that would be delayed (Table 8) using a mathematical expression inserted in the Delay Type field of each affected process module. The expression, *TRIA(, ,) + Bad Weather * TRIA(, ,),* is designed to use the original process times (Table 4) in the first set of parenthesis and the estimated additional delay times due to bad weather (Table 8) in the second set of parenthesis. When the Bad Weather variable retains its default value of zero, the additional process delay time is cancelled out so only the original process delay is experienced. Just like the Equipment Failure Model, specific data for delay likelihoods were not available due to the fact the COASTS experiment summary did not incorporate weather delay data; therefore, the processes that would be delayed and the additional weather delay times in Table 7 are reasonable guesses based on a mixture of reasonable guesses and real issues that surfaced during the dry runs mentioned at the end of Chapter I.

Process Being Delayed	Additional Delay in Minutes
PREP JOCC	5, 30, 90
PREP PCF	10, 30, 60
AU-23 LAUNCH AND TRANSIT TO DISASTER AREA	20, 45, 90
PCF LAUNCH AND TRANSIT TO DISASTER AREA	20, 40, 60
LAUNCH MECP AND BEGIN TRANSIT TO DISASTER AREA	5, 30, 90
MUAV LAUNCH AND TRANSIT TO DISASTER AREA	10, 20, 45
AU-23 SURVEYS DISASTER AREA AND SENDS DATA TO JOCC	5, 10, 15
PCF SURVEYS DISASTER AREA AND SENDS DATA TO JOCC	10, 30, 60
MECP TRANSITS TO DISASTER AREA	10, 20, 60
MECP SETS UP, SURVEYS, AND SENDS DATA TO JOCC	15, 45, 120
MUAV SURVEYS DISASTER AREA AND SENDS DATA TO JOCC	1, 5, 10

Table 7. Processes affected by bad weather with associated delay times

C. COMBINATION MODEL

The Combination Model combines the two previous experiments and is designed to simulate likely delays due to equipment failures and bad weather. It is the Baseline Model with all of the equipment failures and weather delays of the previous two models added in. Since the Equipment Failure Model split the four Survey and Send Data processes into eight processes, the Bad Weather Delay that was originally associated with those processes was applied to the Survey portion and not the *Send Data*. The results and analysis of all models are presented in Chapter V.

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V. RESULTS AND ANALYSIS

The following paragraphs and tables provide summarized results and analysis of all models with variability. More specifically, the goal of this chapter is to show the averages and the ranges and variation when comparing the three experimental models to the Baseline Model, emphasizing the differences between the *Average, Minimum*, and *Maximum* time needed to send data. As previously stated, each model has been replicated 200 times.

A. RESULTS AND ANALYSIS OF AVERAGE TIMES

Table 8 shows *Average Time Until Data Sent.* To understand the results in Tables 8, 9, and 10, a rough critical path analysis was performed based on most likely process delay times. The critical path for this system, defined as path that goes from start to completion which takes the longest, is: *Process C - G - K - L - M - N - O - Q.* The critical path takes a total of 335 minutes using *Most Likely* times from Table 4 and is linked at some point to all other paths. All other paths have significantly lower *Most Likely* times, and therefore have quite a bit of slack.

The Equipment Failure Model average times reflected in Table 8 do not vary much from the Baseline Model averages. There is one significant jump in the *AU23 to JOCC* path of 10 minutes but the remaining communications only took one to two minutes longer. When considering the confidence intervals in Table 9, this difference is not significant. Looking back at Table 6 (details of Equipment Failure Model) it would seem as though there would be a larger time difference in the other five paths. However, this small change is due to a complex set of factors that includes number of replications, probabilities of equipment failure delays, slack time in others paths when compared to the critical path, and the larger difference between the *Most Likely* and *Maximum* times in the Triangular delay. For instance, when looking at the AU-23 to JOCC path which had the largest increase in time, there are three processes in that path that could experience an equipment failure. Each of those occurrences has a 5% probability. This specific path is not the critical path; it does not take nearly as long as the critical path, and has relatively

low delay times. Therefore, though changes occur in leaps on this path they do not necessarily affect the other five paths due to lack of influence on one another or due to the path being connected to takes considerably longer anyway and is not impacted by changes on the shorter path.

	Average Time Until Data Sent For All Models (200 Reps)				
	Script	Baseline	Eqpmt Failure	Bad Weather	Combination
AU23 to JOCC	75	111	121	116	127
PCF to JOCC	75	173	174	180	183
JOCC to MECP	80	205	205	213	216
MUAV to JOCC	160	327	329	342	346
MECP to JOCC	160	372	374	392	390
JOCC to NGO	**165**	**423**	**424**	**444**	**443**

Table 8. Comparison of average times until data sent for all models

	95% Confidence Intervals (based on 200 Reps)			
	Baseline	Eqpmt Failure	Bad Weather	Combination
AU23 to JOCC	[109, 114]	[118, 124]	[113, 120]	[122, 130]
PCF to JOCC	[169, 177]	[170, 178]	[175, 184]	[178, 189]
JOCC to MECP	[201, 210]	[202, 209]	[209, 218]	[209, 220]
MUAV to JOCC	[322, 331]	[324, 334]	[335, 349]	[338, 354]
MECP to JOCC	[365, 378]	[368, 381]	[383, 401]	[381, 399]
JOCC to NGO	[416, 430]	[418, 431]	[435, 453]	[433, 453]

Table 9. 95% Confidence Intervals

The Weather Delay Model on the other hand varied quite distinctly from the Baseline and Equipment Failure Models with significant increases in five out of six average time metrics. These increases can be attributed to the same complex combination of factors mentioned above but it is the details of these factors that help explain the larger increases. The greatest impact on average times is the fact that the Weather Delay Model carries a higher probability of 10% as opposed to the Equipment Delay Models range of 1% to 5%. Additionally, the Weather Delay Model also contains a wider variation of delay times when compared to the Equipment Failure Model, which could account for the *AU-23 to JOCC* average time being smaller when compared to the Equipment Failure Model.

Finally, the Combination Model was expected to show an increase in average times beyond that of the Equipment Failure and Weather Delay Models, especially in the *JOCC to NGO* path (which is on the critical path). The expectation to see a significant increase was due to the fact that the delays would build on each other in turn resulting in higher averages when compared to all other models. This did occur in four out of six communication paths and with reasonable accuracy, as you would expect the Combination Model average times to roughly equal the difference in the Equipment Delay Model and Baseline Average Times added to the Weather Delay Model average times. Of the two paths that did not increase, there was one path that in particular that was extremely difficult to comprehend, the JOCC to NGO path which apparently decreased by one minute. Due to this unexpected result, the experimental models were re-examined to insure there were no model errors, and re-run for 1,000 replications but the results showed little variation with the exception of a reduction in half width. Despite the fact the half-widths were reduced, the confidence intervals continued to overlap and more closely than those shown in Table 9 leading to the conclusion are not significantly different. It is reasonable to conclude that running the models for 5, 10, or 15 thousand replications would further hone in on the true average times but for a system that takes 400+ minutes to complete the mission, determining if one model actually takes half a minute more than another on average is not significant enough to warrant this more extensive analysis. However, it is somewhat surprising that the addition of equipment

delays (the only difference between the Baseline Model and the Equipment Failure Model, as well as between the Weather Model and the Combined Model) is not slightly more noticeable.

B. RESULTS AND ANALYSIS OF MIN AND MAX TIMES

Greater variation is expected when comparing the min and max metrics due to the likelihood of outliers. Tables 10 and 11 show minimum and maximum time results for all models respectively based on 200 simulation replications. These metrics would likely act as a guide for relief workers showing them the earliest and latest likely times they could plan to execute follow on activities. Just like in the average times comparison table, the resulting times in these tables reflect more of the same phenomenon with regard to unexpected results.

	Minimum Time Until Data Sent For All Models (min)				
	Script	Baseline	Eqpmt Failure	Bad Weather	Combination
AU23 to JOCC	75	71	81	69	79
PCF to JOCC	75	97	107	112	114
JOCC to MECP	80	136	143	144	139
MUAV to JOCC	160	225	251	249	255
MECP to JOCC	160	233	270	274	277
JOCC to NGO	**165**	**293**	**312**	**337**	**315**

Table 10. Comparison of minimum times until data sent for all models

	Maximum Time Until Data Sent For All Models (min)				
	Script	Baseline	Eqpmt Failure	Bad Weather	Combination
AU23 to JOCC	75	154	173	200	233
PCF to JOCC	75	238	275	299	299
JOCC to MECP	80	287	312	346	331
MUAV to JOCC	160	422	472	558	552
MECP to JOCC	160	497	508	607	626
JOCC to NGO	**165**	**558**	**554**	**670**	**668**

Table 11. Comparison of maximum times until data sent for all models

When comparing the Equipment Failure Model to the Baseline Model for both min and max, we see that there is an increase in times across the board with the exception of the max time for the *JOCC to NGO* path. This can only be explained in much the same way as the average time phenomenon for the same path above. Since this communication is on the critical path and there is considerable slack on those paths around it, fluctuations in those paths do not affect *JOCC to NGO* path, in this case causing it to actually decrease by 2 minute. That said, all previously mentioned factors such as probabilities of failure and delay combined with variable delay times cannot be overlooked and surely contribute to this unexpected result.

The remaining models show much of the same unexpected pattern when compared to the model that precedes it. Both min and max times would be expected to increase when going from the Baseline Model to the Combination Model respectively but as shown Tables 10 and 11 are littered with data points which prove otherwise.

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VI. CONCLUSIONS AND RECOMMENDATIONS

As previously stated, the COASTS Experiment proved that the damage assessment system tested in this project works and is a realistic option when looking for a system that can provide support in a disaster situation. This project expands on their experiment by using discrete event simulation to determine realistic times for setting up and employing this system. The following discussion provides a wrap up of the project to include conclusions based on model results and recommendations on project improvement and continued research.

This project used the COASTS Experiment as a starting point for a more detailed and realistic study of a specific damage assessment system. A highlight of this project is the difference between the Script Model when compared to the other four models. The considerable difference in average times supports the points made in Chapter I regarding live experiment limitations and the value of DES modeling.

As with any type of research, there are a number of issues that surfaced throughout the study, which provided insight for areas of improvement. The most significant recommendation towards the improvement of this project would be the collection of real data points for use in the models. Despite the fact that the COASTS Experiment was based on a script and that data points used in the simulation model were relatively good estimates based on real experiences, the documenting of real prep times, set up times, flight times, failure times, etc., would provided an even more realistic foundation for these DES models. That said, recording a comprehensive list of data points would have not been reasonable due to the time compression and constraints of the COASTS Experiment, but consideration should be given to conducting future live experiments that involve all activities being acted out from beginning to end. In addition to data points associated with time, recording the effect that severe weather has on the equipment being tested is recommended.

With regard to future research in this area, I would recommend the continued study of damage assessment systems similar to or with the same purpose as the one in this project. In my opinion, although there has been a tremendous amount of research conducted in each subsystem to include HFN's and MUAV's seemingly, little attention has been given to putting these subsystems together in the form of a multi-pronged assessment system capable of providing so much critical information and communication abilities for so many disaster response participants.

APPENDIX A (SCENARIO SCRIPT)

Humanitarian Assistance Phase-1 Scenario Script

00:00 **Phase 1 COMEX**. One hour after the tsunami has hit the coastal region. The CTF-COASTS liaison to COASTS team requests assistance to survey the scope of the disaster and initiate search, rescue, and recovery efforts. After an additional hour of coordination and crisis planning, COASTS has determined how best to support this request and coordinate the support with the host-nation. Time elapsed since Tsunami +02:00.

00:01 JOCC Directs AU-23 Mosquito to be launched from Wing-5 and dispatched to disaster region.

00:01 **JOCC Director** (Ch-1): "Airboss, JOCC, launch alert AU-23 to disaster region."
Airboss (Ch-1): "Roger, launch alert AU-23"

00:01+30 **Airboss** (VHF): "Mosquito 01, Airboss, launch and depart to disaster area, report on ground routes and extent of damage"
Mosquito 01 (VHF): "Roger, launch and depart"

00:02 **Mosquito 01** (VHF-tower): "Ao Manao Tower, Mosquito 01 ready for takeoff, turnout to northwest and departure to south."
Tower (VHF): Provides necessary clearance.

00:02 JOCC Directs Mobile Emergency Command Post (MECP) Team to depart Wing-5 for disaster zone.

00:02 **JOCC Director** (Ch-1): "MECP, JOCC, depart for disaster zone"
MECP (Ch-1): "Roger, departing"

00:03 **JOCC Director** (VOIP): "PCF, JOCC, transit to offshore of disaster region"
PCF (VOIP): "Roger, departing"

00:15 AU-23 arrives over disaster area, video provided to COASTS JOCC and to remote sites via COASTS network. PCF arrives in disaster area.

00:15 **Mosquito 01** (VHF): "JOCC, Mosquito 01, I am over disaster zone now. Coastal zone has sustained significant damage. Buildings and coastal road

appear damaged. Large number of bodies near shoreline or in water. Will transmit video."
JOCC Director (VHF): "Mosquito 01, JOCC, understand significant damage and loss of life, waiting on video"

00:15+30 **PCF** (VOIP): "JOCC, PCF, I am offshore from disaster zone. I confirm report, significant damage and bodies awash in water."
JOCC Director (VOIP): "PCF, JOCC, thank you for confirmation"

00:20 Timeline compression. 60 minutes simulated elapsed. After short survey of disaster area, routes are determined into the area for disaster relief teams. JOCC relays this information to the inbound MECP Team. AU-23 uses loiter capability to remain over area and provide continued SA and support. MECP arrives in disaster area.

00:20 **MECP** (SATCOM): "JOCC, MECP, we have arrived in disaster zone, initiating setup, standby for video, TwiddleNet, and reporting"
JOCC Director (SATCOM): "Roger MECP, JOCC standing by"
JOCC Director (Ch-1): "Lauch UAV"
UAV Site (Ch-1): "Roger JOCC, launching UAV"

00:40 MECP set up complete (including TwiddleNet) and initial reports data-linked back via satellite to COASTS JOCC. Mini-UAV supports MECP, reporting on damage to surrounding area through aerial surveillance.

00:40 **MECP** (SATCOM): "JOCC, MECP, you should be receiving video and TwiddleNet. Coastal region has suffered significant loss of life and damage, this is a major disaster zone. Inland road structure is intact, but refugees are flooding the network. Local communications are down. Medical assistance and housing needs have priority."
JOCC Director (SATCOM): "MECP, JOCC, Roger, will pass your information to higher, continue observation and reporting"

00:45 Reports on damage/scope of disaster relayed from COASTS JOCC to host-nation Command Center and local NGO headquarters in capital.

00:45 **JOCC Director** (Phone): Makes contact with host-nation command center(s) and local NGO headquarters to confirm receipt of information

00:50 Phase 1 FINEX: Mini-UAV recovers. MECP Return to base.

APPENDIX B (COASTS EXPERIMENT SUMMARY)

Key Excerpts Concerning Daytime Final Experiment Taken from

COASTS 27 May 2008 Daily Sitrep

PROGRAM MANAGER'S SUMMARY:

The Cooperative Operations and Applied Science & Technology Studies (COASTS) International Field Experimentation Team conducted its final day of operations at Wing-5 on the Royal Thai Air Force (RTAF) Base in Prachuap Khiri Khan on 27 May 2008. Two scenario runs were successfully conducted, one during the afternoon and one after dark. COASTS participants and observers numbered over one hundred (100) people representing the following organizations:

- Royal Thai Defense Science & Technology Office
- Royal Thai Air Force
- Royal Thai Navy (RTN)
- Royal Thai Navy SEALs
- Royal Thai Naval Research & Development Office (NRDO)
- Royal Thai Military Research & Development Center (MRDC)
- RTN Engineering Officers School
- Petroleum Authority of Thailand (PTT)
- Electrical and Electronics Products Testing Center (PTEC)
- Naval Postgraduate School (NPS) faculty and students
- U.S. Special Operations Command (USSOCOM)
- Defense Information Systems Agency (DISA)
- Office of Naval Research (ONR) reservists
- U.S. Army Training and Doctrine Command (TRADOC) Analysis Center/Engineering Research and Development Center (TRAC-ERDC)
- U.S. Air Force 37th Security Forces Squadron
- Naval Surface Warfare Center-Panama City Division (NSWC-PCD)
- U.S. Marine Forces Pacific (MARFORPAC)
- MARFORPAC Experimentation Center (MEC)
- III Marine Expeditionary Force (MEF)
- Joint U.S. Military Advisors Group Thailand (JUSMAGTHAI)
- Embassy of Greece
- Hellenic Air Force
- Turkish Air Force
- Numerous industry and commercial partners

1. MAJOR ACCOMPLISHMENTS

- Successfully ran all Scenario Phases (1, 2A, 2B, 3) during the day time using a compressed timeline.
- Successfully ran Scenario Phases 2A and 2B during the night.

- Hosted several arriving VIPs including Lieutenant General Apichart (Director General DSTO), Major General Thitinant (Deputy Director General DSTO), Air Vice Marshal Wanchai (Special Projects Officer, DSTO), Air Vice Marshal Thanongsak (RTAF Security Force Command), Mr. Constantine Danassis (Deputy Head of Mission, Embassy of Greece) and Mr. Niyazi Evren Akyol (First Secretary, Turkish Embassy).

2. KEY ISSUES

- A power outage during the morning knocked the Digital Video Recorder out despite being connected to an Uninterrupted Power Supply (UPS).
- CyberBug UAV was down and was not used in the experiment.
- C-View Periscope is not functioning properly and was not used in the scenario.
- One Compact Remote Imaging Sensing System with Two-π+ OutLook (CRISSTL) Ball was broken during operations.

<u>***Skip 3, Jump to 4</u>

4. SYSTEMS STATUS

4.1 Network

a. Achievements

- Network Team resuscitated the network and all associated systems from a JOCC power outage.

4.1.A TwiddleNet

a. Achievements

- Phase 1: SUCCESS
  - Backhaul link: Good
  - Humanitarian Assistance site setup: SUCCESS
    - Setup complete in less time allotted in scenario script.
- Video / picture with data was received at JOCC .
  - Multithreading: SUCCESS
    - All TwiddleNet handhelds were able to retrieve data from other handhelds.
    - Pictures were displayed on server laptop for instantaneous streaming.
- Radio Communications: SUCCESS
- Thai counterparts as tsunami survivors: SUCCESS

4.7.A Unmanned Air Vehicles (UAVs)

a. Achievements

- Video successfully transmitted through the AeroVironment (AV) Decoder application and displayed in the JOCC. Additionally, Axis web servers were used as well to display video via a web interface.

- Conducted two Raven UAV flights in support of the day/night scenario. Conducted one additional Raven flight after the night scenario in order to show additional IR capability.

b. Near-Term Plans/Events

- Nothing to report.

c. Comments/Issues

- During the day scenario a lost communication issue between the AU-23 and the tower caused the Raven UAV to move into a holding pattern. In addition, a Citation aircraft made an emergency landing during the scenario. These issues impacted the loiter time by 10 minutes during the scenario. We have to ensure that contingencies/emergencies are cover in depth prior t launching in future field experiments. Specifically, all players need to be aware of contingency plans including scenario delay, hold position and altitude and recovery plans.

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APPENDIX C (EQUIPMENT OPERATOR SURVEY)

Questionnaire

Performance Feedback on Specific Surveillance and Data Collection Platforms

Principle Investigator: Captain Richard J. Bridgett, USMC, Student, GSBPP, NPS

Project Title: Analysis of Specific Surveillance and Data Collection Platforms Used in Response to a Tsunami

Background: In May of 2008, the NPS based Cooperative Operations and Applied Science and Technology Studies (COASTS), conducted their 5th and final exercise of fiscal year 2008 in Ao Manao, Thailand. Ao Manao is located on the Thai Peninsula, on the gulf side, and is home to Wing 5 of the Royal Thai Air Force (RTAF). All experiments for exercise 5 were conducted aboard the RTAF base.

Scenario 1 of exercise 5 (listed below) was an experiment that tested specific surveillance and data collection platforms with the purpose of giving the Joint Operations Center (JOC) an operational picture of the affected area. This operational picture was then transmitted to multiple emergency response and support agencies throughout the regional and international community allowing for a more efficient support effort.

Task: Using the script below as an established guideline, please answer the questions that follow the script to the best of your recollection. The questions will cover the following areas:

- Equipment tested
- Time with regard to script
- Problems encountered with the performance of the equipment
- Problems encountered due to external factors
- Additional comments

*****FEEL FREE TO USE EXCERPTS FROM TECHNICAL DOCS, IN-PROGRESS OR COMPLETED THESIS, ETC…ETC…THE MORE INFORMATION THE BETTER!**

For Script, reference Appendix A

QUESTIONS BELOW↓

QUESTIONS

(use as much space as required to answer questions, the more the better!)

1. Please provide in as much detail as possible a description of the equipment you tested and what its purpose was in the scenario 1 experiment. If applicable, please include technical specs, references, websites and any other resources which may help explain your answers.

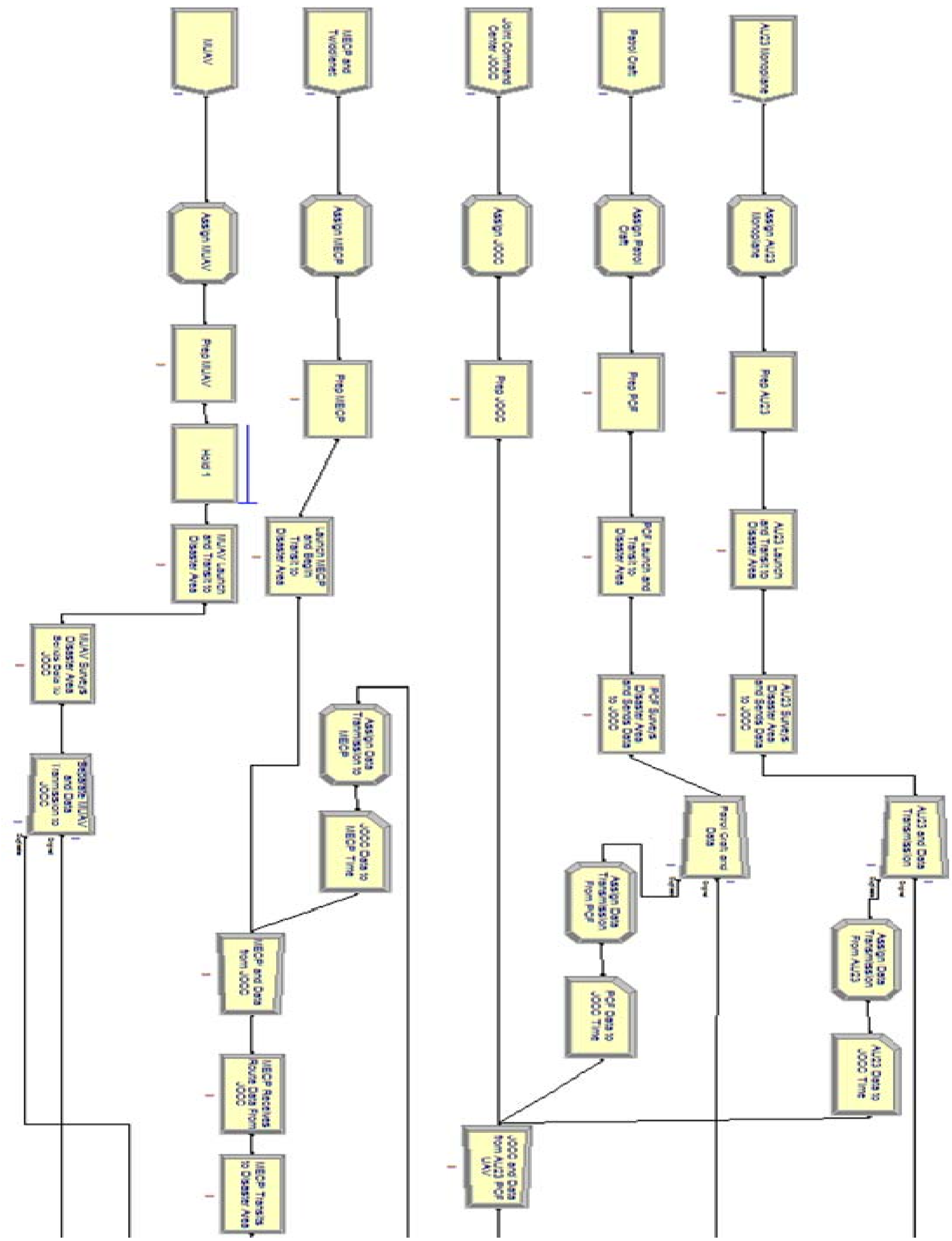
2. Please provide in a as much detail as possible an explanation as to how the equipment you tested compared to the timeline provided in the script above, i.e. the MECP took much longer to set up than the script depicted therefore throwing off the timeline, etc…and here is why…

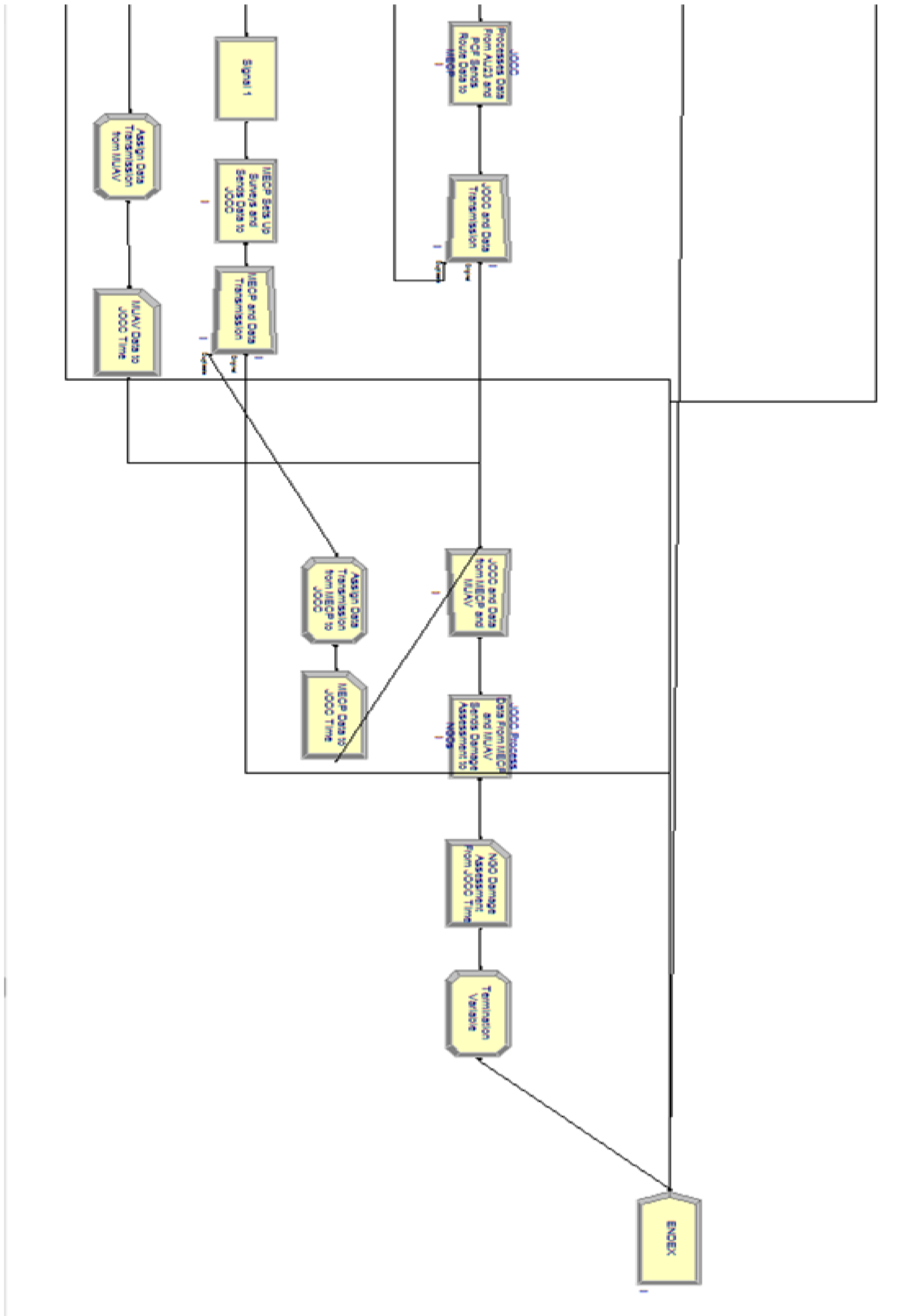
3. Please provide in as much detail as possible an explanation of any and all problems/issues you had with the equipment you were testing while the experiment was being conducted to include problems that prevented you from participating in the scenario 1 experiment or in portions of it.

4. Please provide in as much detail as possible an explanation of any external problems (not related to equipment, i.e. weather, clearance from flight tower, etc…) that prevented you from participating in the scenario 1 experiment or in portions of it.

5. Any additional comment.

APPENDIX D (ARENA SIMULATION MODEL: BASELINE)





Signal 1
MEOP Sets Up Surveys and Sends Data to JOCC
MEOP and Data Transmission
Assign Data Transmission from MUAV
MUAV Data to JOCC Time
JOCC and Data Transmission
JOCC and Data from MEOP and MUAV
Assign Data Transmission from MEOP to JOCC
MEOP Data to JOCC Time
NOC Damage Assessment from JOCC Time
Termination Variable
ENDEX

LIST OF REFERENCES

Abuan, Lillian. "Performance feedback on specific surveillance and data collection platforms." Naval Postgraduate School. 15 September 2008.

AeroVironment, Inc. "AeroViroment ". AeroVironment, Inc. Retrieved on 20 November 2008, from <http://www.avinc.com/>

Ehlert, James. “COASTS 2008 Field Exercise V Daily Sitrep (Final).” 27 May 2008.

Kelton, W. David, Sadowski Randall P., and Sturrock David T. Simulation with arena, Fourth Edition. New York: McGraw-Hill, 2007.

Mishoe, Michael. "Performance feedback on specific surveillance and data collection platforms." Naval Postgraduate School. . 15 September 2008.

Wikipedia, "Royal Thai Navy." Wikimedia Foundation, Inc. 21 November 2008 <http://en.wikipedia.org/wiki/Royal_Thai_Navy>.

Wikipedia, "Royal Thai Air Force." Wikimedia Foundation, Inc. 20 November 2008 <http://en.wikipedia.org/wiki/Royal_Thai_Air_Force>.

Wikipedia, "Pilatus PC-6." Wikimedia Foundation, Inc. 20 November 2008 <http://en.wikipedia.org/wiki/Pilatus_PC-6>.

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